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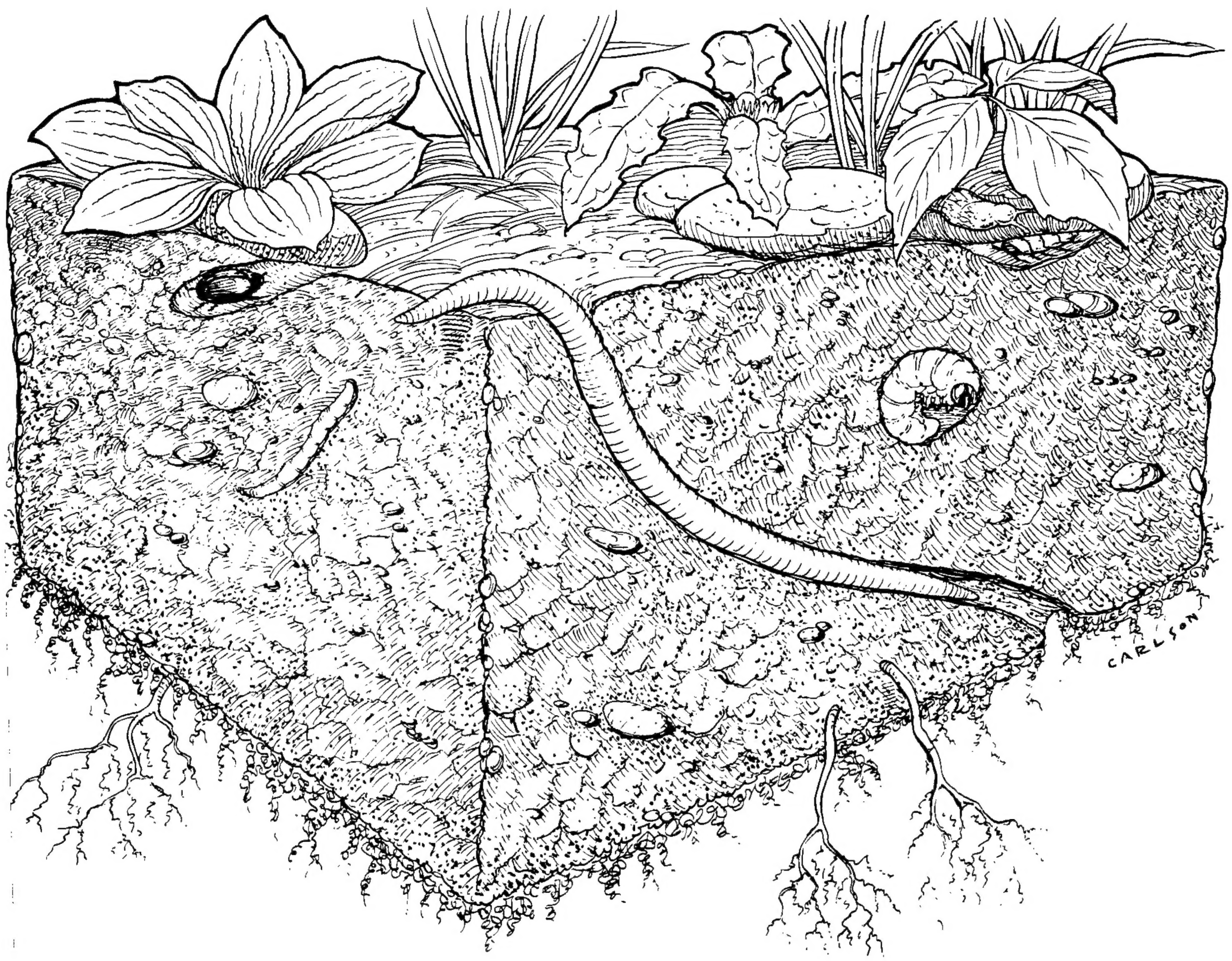
Evaluating Soil Contamination



Fish and Wildlife Service
U.S. Department of the Interior

Biological Report

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July 1990

Evaluating Soil Contamination

by

W. Nelson Beyer

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Preface

This compilation is designed to help contaminant specialists evaluate environmental hazards from contaminants in soil and in similar materials, such as dredged material. This should be used with the contaminant index. Included in this compilation are regulatory criteria, opinions, citations, brief descriptions of scientific articles, and miscellaneous information that might be useful in making risk assessments of soil contaminants. The material was compiled because little information is available to assist field personnel who must evaluate soil contamination at local sites. Many of the guidelines that have been developed are not known outside specialized fields of regulation and cannot be found through a literature search. In contrast, many volumes have been published that review contaminants in general or contaminants in aquatic systems. My intent is to provide access to hard-to-obtain material that might be helpful in making sound decisions. Thus, this report includes information on what those in related fields consider hazardous, and includes citations to articles that might be useful in making a risk assessment for wildlife.

Many seemingly different environmental problems actually have much in common. For example, whether sediments are to be dredged and disposed of on land, sewage sludge is to be applied to farmland, or a hazardous waste site is to be cleaned up, all involve estimating contaminant concentrations that should be considered safe in each situation. Although the concentration considered safe depends on the particular situation, risk assessments of different habitats are likely to share common lines of reasoning.

Researchers disagree over how best to evaluate hazards from soil contaminants. Some researchers deny the value of using concentrations at all and prefer bioassays; others stress the inadequacy of the data available to derive guidelines and use background concentrations and their best judgment for selecting a value; yet others swear by risk assessment. I made no attempt to judge the material presented or to endorse particular approaches. The choice is left entirely to the reader.

The descriptions included are brief. When describing limitations on applying sludge to land, for example, I included only information on the total cumulative amounts that may be applied to soil, since they seemed most relevant. Sludge regulations include a great deal more information, such as how and where sludge may be applied, limits on nitrogen, and so on. For each published reference only enough information is included to indicate its relevance to the topic; all of the howevers, contrariwises, and admonitions about leaping to hasty conclusions are left out. If data are to be cited, the reader should go to the original source to be sure that the intent of the author is understood. Some of the information included is from drafts. Unfortunately, many of the criteria did not have accompanying explanations of how they were derived, and this limits their application to other situations.

Concentrations in soil should be assumed to be expressed as dry weight, unless stated otherwise. Most of the regulations limiting the addition of environmental contaminants with sludge have been expressed as maximum kilograms per hectare, but they may still be helpful for evaluating concentrations; if we assume that contaminants are mixed into a plow layer (about 15 cm) that weighs 2,000,000 kg/ha, then 2 kg/ha of a contaminant would be equivalent to 1 ppm in that plow layer.

The first 10 entries are from various countries and are standards or recommended guidelines for evaluating contaminated soil. Entry 2, from the Netherlands, is particularly useful if the reader does not require that the criteria be supported with a risk assessment, because this entry includes most of the contaminants generally considered hazardous. Entry 10, from the Soviet Union, includes maximum allowable concentrations for even more chemicals, but regrettably, I did not learn anything about the reasoning behind their derivation. Six of the entries come from an unpublished report by G. Mark Richardson, entitled "Inventory of Cleanup Criteria and Methods to Select Criteria," prepared for the Committee on Industrial Site Decommissioning, Environment Canada, in March 1987. This is an excellent reference for evaluating hazardous waste sites. Federal, State, and European Economic Community guidelines limiting the maximum cumulative amounts of contaminants that may be added to soil with sewage sludge are found in entries 11–23. These are followed by estimates of contaminants in sewage sludges (entries 24 and 25). Entry 26 provides estimates of elemental concentrations of surficial materials, and entries 27–29 list guidelines for evaluating contaminants in sediments. The rest of the entries are brief descriptions of published scientific articles that might be useful in making risk assessments. Articles on the accumulation of contaminants by earthworms are emphasized, because earthworms are a natural bridge for contaminants between soil and many wildlife species. Many articles have been published on the accumulation of elements by earthworms, and several reviews are available; consequently, this topic was treated only briefly in entry 51. Entry 56 lists recommended references on earthworm biology. Other entries include citations to articles on the toxicity of metals in litter to woodlice (entry 58), human health hazards from soil lead and TCDD (entries 59–61), and the ingestion of polychlorinated biphenyls (PCB's) from soil by grazing animals (entry 62).

I thank T. J. Miller and D. Schultz for their reviews, and T. Kubiak for sending much useful material.

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Evaluating Soil Contamination

by

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ABSTRACT.—This compilation was designed to help U.S. Fish and Wildlife Service contaminant specialists evaluate the degree of contamination of a soil, based on chemical analyses. Included are regulatory criteria, opinions, brief descriptions of scientific articles, and miscellaneous information that might be useful in making risk assessments. The intent was to make hard-to-obtain material readily available to contaminant specialists, but not to critique the material or develop new criteria. The compilation is to be used with its index, which includes about 200 contaminants. There are several entries for a few of the most thoroughly studied contaminants, but for most of them the information available is meager. Entries include soil contaminant criteria from other countries, contaminant guidelines for applying sewage sludge to soil, guidelines for evaluating sediments, background soil concentrations for various elements, citations to scientific articles that may help estimate the potential movement of soil contaminants into wildlife food chains, and a few odds and ends. Articles on earthworms were emphasized because they are a natural bridge between soil and many species of wildlife.

Soil Contamination Criteria

Japan

(1) Japanese Environmental Administration. Present state and tasks of soil pollution control measures in Japan. Unpublished report, Tokyo, Japan. 17 pp.

The Japanese Environmental Administration has developed criteria for evaluating soil pollution of public land to protect human health. When criteria are exceeded the area must be cleaned up, such as by covering the area with uncontaminated soil. The criteria for identifying soil polluted with arsenic (50 ppm), cadmium (9 ppm), lead (600 ppm), and mercury (3 ppm) were established as the mean value of soils surveyed plus three times the standard deviation. Pollution by hexavalent chromium, alkyl mercury compounds, organic phosphorous compounds, cyanides, and PCB's is evaluated after an elution test.

Agricultural Land Soil Pollution Prevention, Etc., Law No. 139 of 1970, amended by Law No. 88 of 1971 and Law No. 87 of 1978.

Cabinet Order for Implementation of the Agricultural Land Soil Pollution Prevention, Etc., Law. Cabinet Order No. 204 of 1971, amended by Cabinet Order No. 219 of 1971, No. 375 of 1972, and No. 103 of 1975.

Agricultural land is designated as "agricultural land soil pollution policy areas" if the copper concentration exceeds 125 ppm (0.1 N HCl extraction), the arsenic concentration exceeds 15 ppm (1 N HCl extraction), or the cadmium concentration in rice grown in the soil is 1 ppm or more. Once this designation is made the prefectural governor must design a plan to prevent or eliminate the soil pollution.

Netherlands

(2) Soil Cleanup (Interim Act)

Richardson, G. M. 1987. Inventory of cleanup criteria and methods to select criteria. Unpublished report, Committee on Industrial Site Decommissioning, Industrial Programs Branch, Environment Canada, Ottawa, Ontario K1A 1G2. 46 pp.

Extensive criteria for determining the need for soil cleanup have been developed in the Netherlands (Table 1). In this system, criteria A refer to background concentrations in soil or detection limits, criteria B refer to moderate soil contamination that requires additional study, and criteria C refer to threshold values that require immediate cleanup.

Table 1. *Soil criteria for evaluating the severity of contamination under the Dutch Soil Cleanup (Interim) Act (from Richardson 1982).*

	Indicators (ppm)		
Contaminant category	A	B	C
Heavy metals			
Arsenic	20	30	50
Barium	200	400	2,000
Cadmium	1	5	20
Chromium	100	250	800
Cobalt	20	50	300
Copper	50	100	500
Lead	50	150	600
Mercury	0.5	2	10
Molybdenum	10	40	200
Nickel	50	100	500
Tin	20	50	300
Zinc	200	500	3,000
Mineral pollutants			
Bromine (total)	20	50	300
Cyanide, free (total)	1	10	100
Cyanide, complex (total)	5	50	500
Fluorine (total)	200	400	2,000
Sulfur (total)	2	20	200
Monocyclic aromatic hydrocarbons (MAH)			
Benzene	0.1	0.5	5
Ethylbenzene	0.05	5	50
Toluene	0.05	3	30
Styrene	0.05	5	50
Xylene (total)	0.05	5	50
Total MAH's	0.10	7	70
Phenolic compounds			
Phenols (excluding chlorophenols)	0.02	1	10
Chlorophenols (each)	0.01	0.5	5
Chlorophenols (total)	0.01	1	10
PAH's			
Anthracene	0.1	10	100
Benzo(a)pyrene	0.1	1	10
Fluoranthene	0.1	10	100
Napththalene	0.1	5	50
Phenanthrene	0.1	5	50
Pyrene	0.1	10	100
Total PAH's	1	20	200
Chlorinated hydrocarbons			
Aliphatic chlorinated hydrocarbons (each)	0.1	5	50
Aliphatic chlorinated hydrocarbons (total)	0.1	7	70
Chlorobenzene (each)	0.05	1	10

Table 1. *Continued.*

Contaminant category	Indicators (ppm) A	B	C
Chlorobenzene (total)	0.05	2	20
Polycyclic chlorinated hydrocarbons (total)	0.1	1	10
PCB's (total)	0.05	1	10
Total chlorinated hydrocarbons	0.1	8	80
Pesticides			
Organochlorinated (each)	0.1	0.5	5
Organochlorinated (total)	0.1	1	10
Total Pesticides	0.1	2	20
Other pollutants			
Cyclohexane	0.1	6	60
Gasoline	20	100	800
Mineral oils	100	1,000	5,000
Pyridine	0.1	2	20
Styrene	0.1	5	50
Tetrahydrofuran	0.1	4	40
Tetrahydrothiophene	0.1	5	50

Canada

(3) Texaco and Shell Soil Cleanup Criteria for Ontario Refineries

Richardson, G. M. 1987. Inventory of cleanup criteria and methods to select criteria. Unpublished report, Committee on Industrial Site Decommissioning, Industrial Programs Branch, Environment Canada, Ottawa, Ontario K1A 1G2. 46 pp.

The Ontario Ministry of the Environment required that Texaco Canada, Inc. and Shell Canada, Ltd. set the soil cleanup criteria to be used in dismantling two oil refineries (Table 2). Based on an exposure model for human health, the criteria were set to ensure that the intake by humans through dust and other routes of exposure would not exceed the acceptable daily intake.

Table 2. *Acceptable on-site soil concentrations approved by the Ontario Ministry of the Environment for the Texaco and Shell refinery sites*[a] *(from Richardson 1987).*

Substance	Acceptable soil concentration (ppm)
Benzene	0.040–0.13
Benzo(a)pyrene	0.004–0.005
bis(2-ethylhexyl)phthalate	70–5,000
Chrysene	470
Cresols	700
1,4-Dioxane	5.80–12.2
Ethylene dibromide	0.00006
Methyl ethyl ketone	52
Naphthalene	5,400
Phenanthrene	1,870

[a] Based on range of acceptable daily intakes and the highest total dose estimate.

(4) Soil Cleanup near Lead Smelters in Ontario and Manitoba

Richardson, G. M. 1987. Inventory of cleanup criteria and methods to select criteria. Unpublished report, Committee on Industrial Site Decommissioning, Industrial Programs Branch, Environment Canada, Ottawa, Ontario K1A 1G2. 46 pp.

Soils in the vicinity of secondary lead smelters should contain less than 2,600 ppm lead or cleanup is required. The value was derived from consideration of possible soil ingestion by children.

(5) Guidelines for the Decommissioning of Industrial Sites in Ontario

Richardson, G. M. 1987. Inventory of cleanup criteria and methods to select criteria. Unpublished report, Committee on Industrial Site Decommissioning, Industrial Programs Branch, Environment Canada, Ottawa, Ontario K1A 1G2. 46 pp.

The guidelines for cadmium, lead, and mercury were developed to protect human health, those for molybdenum and selenium to protect animal health, and the rest on the basis of phytotoxicity (Table 3).

Table 3. *Soil cleanup criteria for decommissioning industrial sites in Ontario*[a] *(from Richardson 1987).*

	Criteria for proposed redevelopment[b]		
Parameter	Agriculture[c]	Residential/Parkland[d,e]	Commercial/Industrial[d,e]
Arsenic	14	25	50
Cadmium	1–6	4	8
Chromium (6+)	—	10	10
Chromium (total)	120	1,000	1,000
Copper	100	300	300
Electrical conductance (mS/cm)	—	2	2
Lead	60	500	1,000
Mercury	0.5	1	2
Molybdenum	4	5	40
Nickel	32	200	200
Nitrogen (%)	—	0.6	0.6
Oil and grease (%)[f]	—	1	1
pH	—	6–8	6–8
Selenium	1.6	5	—
Silver	—	25	50
Sodium absorption ratio	—	15	15
Zinc	220	800	800

[a] From "Guidelines for the Decommissioning (shutdown) of Major Industrial Sites in Ontario," by the Ontario Ministry of the Environment, 1986 (draft).
[b] All units in ppm unless otherwise stated.
[c] Refer to "Guidelines for Sewage Sludge Utilization on Agricultural Lands," available from Ontario Ministry of the Environment.
[d] Cleanup criteria recommended by Phytotoxicology Section, Air Resources Branch, Ontario Ministry of the Environment.
[e] For coarse-textured (sandy) mineral soils, the criteria for metals and metaloids should be reduced by one-half.
[f] Criterion given is for fresh oil; for weathered oil, the criterion is 2%.

(6) Soil Contaminant Guidelines for Alberta

Richardson, G. M. 1987. Inventory of cleanup criteria and methods to select criteria. Unpublished report, Committee on Industrial Site Decommissioning, Industrial Programs Branch, Environment Canada, Ottawa, Ontario K1A 1G2. 46 pp.

Monenco Consultants, Ltd. prepared guidelines in 1985 for Alberta to be used with site-specific information when deciding whether an industrial site must be cleaned up before the land can be used for other purposes (Table 4). The guidelines were based on phytotoxicity and potential accumulation in humans, plants, and wildlife.

Table 4. *Suggested cleanup guidelines for inorganic contaminants in acidic soils in Alberta (from Richardson 1987; prepared by Monenco Consultants, Ltd).*

Element	Acceptable level for acidic soils (pH<6.5) (ppm)
Cadmium	1.0
Chromium	600
Cobalt (preliminary)	100
Copper	200
Lead	800
Nickel	250
Zinc (sheep diet)	100
Zinc (others)	700

(7) Soil Cleanup Criteria for Quebec

Richardson, G. M. 1987. Inventory of cleanup criteria and methods to select criteria. Unpublished report, Committee on Industrial Site Decommissioning, Industrial Programs Branch, Environment Canada, Ottawa, Ontario K1A 1G2. 46 pp.

The Province of Quebec slightly modified the criteria developed in the Netherlands for evaluating soil contamination. As in the Dutch system, criteria A refer to background concentrations in soil or detection limits, criteria B refer to moderate soil contamination that requires additional study, and criteria C refer to threshold values that require immediate cleanup. Only contaminants with criteria different from the Dutch criteria are shown in Table 5.

Table 5. *Quebec soil contamination indicators that differ from those of the Netherlands (from Richardson 1987).*

Contaminant	Category (ppm)		
	A	B	C
Benzo(a)anthracene	0.1	1	10
Benzo(a)phenanthrene	0.1	1	10
Cadmium	1.5	5	20
Chrysene	0.1	5	50
Dibenz(a,h)anthracene	0.1	1	10
Dibenz(a,h)pyrene	0.1	1	10
Dimethylbenz(a)anthracene	0.1	1	10
Hexachlorobenzene	0.1	1	10
Indeno(2,3,c,d)pyrene	0.1	1	10
Lead	50	200	600
Molybdenum	5	10	40
Selenium	1	3	10
Silver	5	10	40
Zinc	200	500	1,500

United States

(8) California Guidelines for Leaking Underground Fuel Tanks

California State Leaking Underground Fuel Tank Task Force. 1988. Leaking underground fuel tank field manual: guidelines for site assessment, cleanup, and underground storage tank closure. State Water Resources Control Board, 901 P Street, P.O. Box 100, Sacramento, California 95801.

A field manual was developed for determining the extent of cleanup required to protect public health and the environment from leaking underground fuel tanks. At most sites, the principal aim is to protect groundwater. Each site is designated as having a high, medium, or low leaching potential based on such considerations as depth to groundwater, average precipitation, and the presence of structures that might increase the rate of flow through the soil. Soils having a low leaching potential would be removed if the benzene concentration exceeds 1 ppm; if the toluene, xylene, or ethylbenzene concentration exceeds 50 ppm; or if the total petroleum hydrocarbon concentration exceeds 1,000 ppm. The corresponding values for soil having a medium leaching potential are 0.3 ppm benzene, 0.3 ppm toluene, 1 ppm xylene, 1 ppm ethylbenzene, and 100 ppm total petroleum hydrocarbons. If the soil has a high leaching potential, then the total petroleum hydrocarbons must not exceed 10 ppm.

(9) The New Jersey Environmental Cleanup Responsibility Act

New Jersey Department of Environmental Protection. 1987. Summary of approaches to soil cleanup levels. Division of Waste Management, 32 East Hanover Street, Trenton, New Jersey 08628.

Guidelines for the substances listed in Table 6 were derived by considering background concentrations and selecting a multiple of the background concentrations, thought to ensure that concentrations in groundwater would not violate drinking water standards. At certain kinds of sites, higher concentrations may be allowed. The guidelines for organic contaminants are relatively conservative and are designed to identify potential problems. They are not necessarily cleanup objectives.

Table 6. *Guidelines for the New Jersey Environmental Cleanup Responsibility Act (from New Jersey Department of Environmental Protection 1987).*

Substance	Soil (ppm)
Arsenic	20
Barium	400
Beryllium	1
Cadmium	3
Chromium	100
Copper	170
Lead	250 – 1,000
Mercury	1
Nickel	100
Selenium	4
Silver	5
Zinc	350
Total volatiles	1
Base neutrals	10
Petroleum hydrocarbons	100

Soviet Union

(10) Maximum Allowable Soil Concentrations

USSR State Committee for Science and Technology. 1984. Maximum allowable concentrations and tentative safe exposure levels of harmful substances in the environmental media. United Nations Environment Programme, Centre of International Projects, GKNT, 16, Avenue Jean-Trembley, Petit-Saconnex, 1209. Geneva, Switzerland. 114 pp.

"The maximum allowable concentration of a substance in soil is its concentration at which the substance does not enter the plants, water, or air in amounts that exceed the respective maximum allowable concentration for these media and has no adverse effects on the composition and biological properties of the soil" (Table 7).

Table 7. *Maximum allowable concentrations (MAC) and tentative allowable concentrations (TAC) of pesticides and other substances in soil in the Soviet Union (from USSR State Committee for Science and Technology 1984).*

Substance	MAC (ppm)	TAC (ppm)
Abate		0.6
Acetaldehyde	10	
Amiben		0.5
Antimony	4.5	
Arsenic	2.0	
Atrazine	0.5	
Basudin	0.2	
Benzene	0.3	
Benzo(a)pyrene	0.02	
Bromophos		0.4
Butylate		0.6
Carbaryl	0.05	
Carbophos	2	
Chloramp	0.05	
Chlorophos	0.5	
Chromium	0.05	
Copper (extractable with ammonium acetate buffer)	3.0	
Cumene	0.5	
Cyanox		0.4
Cycloate	0.8	
2,4-D	0.1	
2,4-D, ammonium salt	0.25	
Dacthal		0.1
Dalapon sodium	0.5	
DDT	0.1	
Desmetryn		0.6
Dicamba	0.25	
2,4-Dichlorophenol	0.05	
Dichlorvos		0.1
Dihydroheptachlor	0.5	
Dimethoate	0.3	
Dinobuton	1.0	
Diuron		0.6
Endosulfon		0.1
Eptam	0.9	
Etaphos		0.1
Fenuron	1.8	
Folpet		0.3
Formaldehyde	7.0	
Gardona	1.4	
Glyphosate	0.5	
Heptachlor	0.05	
Herban		0.7
Heterophos	0.05	
Hexachlorobutadiene	0.5	
Hexachlorocyclohexane	0.1	
Kelthane	1.0	
Lead	20.0	
Lenacil		0.1
Lindane	0.1	
Linuron	1.0	
Manganese	1,500	
Mercury	2.1	
Metathione	1.0	
Methaphos	0.1	
Monolinuron		0.7

Table 7. *Continued.*

Substance	MAC (ppm)	TAC (ppm)
Monuron		0.6
Nickel (extractable by ammonium acetate buffer, pH = 4.6)	4.0	
Nitrates	130	
Nitrofor		0.2
Pebulate		0.6
Permethrin		0.05
Phenazon		0.7
Phenthoate		0.4
Phosalone	0.5	
Phosphorus pentoxide	200	
Phthalophos	0.1	
Picloram	0.05	
Pirimicarb	0.3	
Pirimiphos-methyl	0.5	
Pirimiphos-methyl (soil pH = 5.5)	0.1	
Polychlorocamphene	0.5	
Polychloropinewe	0.5	
Polytriazin (mixture of atrazine, simazine, and propazine)	0.01	
Prometrin	0.5	
Propanid	1.5	
Simazin	0.2	
Solan		0.6
Tenoran		0.4
Terbacil		0.4
Toluene	0.3	
Toxaphene	0.5	
Treflan		0.1
Vanadium	150	
Yalan		0.9
Zinc (extractable by ammonium acetate buffer, pH = 4.8)	23	
Zineb	1.8	

[a] The MAC's and TAC's are taken from the "International Register of Potentially Toxic Chemicals," United Nations Environment Programme, Geneva, Switzerland. 1988. 16. Avenue Jean-Trembley, Petit-Saconnex, 1209 Geneva, Switzerland.

Sewage Sludge

Guidelines for Limiting Additions of Contaminants

(11) U.S. Environmental Protection Agency (Cadmium and PCB's)

Federal Register, Vol. 44, No. 179, Thursday, 13 September 1979, Environmental Protection Agency, 40 CFR Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices. 53438–53468.

The U.S. Environmental Protection Agency has determined criteria limiting the annual and cumulative amount of cadmium that may be added to soil used for the production of crops for human consumption. If soil pH is below 6.5 then a maximum of 5 kg/ha (dry weight) may be applied. If soil pH is equal to or above 6.5 then the maximum that may be applied is 5 kg/ha if the cation exchange capacity (CEC) is less than 5 meq/100 g, 10 kg/ha if the CEC is 5–15 meq/100 g, and 20 kg/ha if the CEC is greater than 15 meq/100 g. These values were derived from a model relating increased cadmium intake in humans to possible renal damage in that portion of the population at greatest risk. If sludge is applied to land used for growing animal feed or for nonagricultural purposes then the limits do not apply. If sewage sludge contains from 10–50 ppm PCB's then the sewage sludge must be incorporated into the soil if the land is to be used for animal feed or as pasture. If the concentration exceeds 50 ppm then the sludge should be incinerated

or put into a chemical waste landfill. PCB's are thought to be most likely to enter the human food chain if sludge containing them adheres to vegetation and is ingested by animals.

(12) U.S. Environmental Protection Agency (Lead)

U.S. Environmental Protection Agency, U.S. Food and Drug Administration, and U.S. Department of Agriculture. 1981. Land application of municipal sewage sludge for the production of fruits and vegetables: a statement of Federal policy and guidelines. 21 pp.

The maximum cumulative amount of lead added to soil with sewage sludge to land used for growing fruits and vegetables should not exceed 800 kg/ha. This recommended limit was set to protect human health.

(13) Florida

Florida Department of Environmental Regulation. 1985. Resource recovery and management. Bureau of Waste Management, 2600 Blair Stone Road, Tallahassee, Florida 32399.

Domestic wastewater treatment sludges in Florida are classified into three grades. Grade 1 sludge is the least contaminated with metals, grade 2 sludge is moderately contaminated, and grade 3 sludge is the most contaminated. A grade 3 sludge cannot be spread on land used for growing agricultural crops. The criteria for a grade 3 sludge are cadmium >100 ppm, copper >3,000 ppm, lead >1,500 ppm, nickel >500 ppm, or zinc >10,000 ppm. The total cumulative additions of metals when grade 2 sludge is applied to agricultural land are 5 kg/ha cadmium, 125 kg/ha nickel, 125 kg/ha copper, 250 kg/ha zinc, and 500 kg/ha lead.

(14) Illinois

Illinois Rules and Regulations, Title 35: Environmental Protection, Subtitle C: Water Pollution, Chapter II: Illinois Environmental Protection Agency, Part 391, Design criteria for sludge application on land, 1 January 1984, Springfield, Illinois.

Illinois guidelines for applying sewage sludge to agricultural land were developed to protect the food chain and to prevent phytotoxicity and water pollution. For a soil with a CEC of 5–15 meq/100 g, the maximum cumulative additions of metals with sewage sludge are 1,120 kg/ha lead, 1,008 kg/ha manganese, 560 kg/ha zinc, 280 kg/ha copper, 112 kg/ha nickel, and 11 kg/ha cadmium. Sewage sludge should not, in general, be applied to soil with a lower CEC, but if it is applied, the maximum cumulative additions are reduced by half. If the soil CEC exceeds 15 meq/100 g then the maximum cumulative additions are doubled. If the Illinois Environmental Protection Agency determines that other metals should restrict the application of sewage sludge to land then the following maximum cumulative additions apply: 784 kg/ha antimony, 112 kg/ha arsenic, 3,920 kg/ha trivalent chromium, 493 kg/ha hexavalent chromium, 8 kg/ha selenium, and 199 kg/ha silver.

(15) Maryland

Code of Maryland Regulations 26.04.06.09. 1986. Sewage sludge management. Department of the Environment, 201 Preston Street, Baltimore, Maryland 21201.

Sewage sludge may not be applied to agricultural land if the amount of metals per acre exceeds established criteria, which are dependent on the CEC of the soil (Table 8).

The maximum concentration of PCB's in soil must not exceed 2 ppm, and the maximum concentration of lead in soil must not exceed 445 ppm if the CEC is less than 5 meq/100 g or 600 ppm if the CEC is 5 meq/100 g or greater.

Table 8. *Maximum cumulative addition of metals (kg/ha) from sewage sludge to Maryland agricultural soil (from Code of Maryland Regulations 1986).*

Metal	Soil cation exchange capacity (meq/100 g)	
	<5	≥5
Cadmium	5	10
Copper	140	280
Lead	560	1,120
Nickel	140	280
Zinc	280	560

(16) Massachusetts

Massachusetts Department of Environmental Quality Engineering. 1983. 301 CMR 32, Regulation for the land application of sludge and sewage. Department of Environmental Quality Engineering, One Winter Street, Boston, Massachusetts 02108.

Sewage sludge may not be applied to land in Massachusetts if the total cumulative amounts per hectare exceed the established guidelines (Table 9).

Table 9. *Maximum cumulative addition of metals (kg/ha) from sewage sludge to Massachusetts agricultural soil (from Massachusetts Department of Environmental Quality, Engineering 1983).*

Metal	Soil cation exchange capacity (meq/100 g)	
	<5	>5
Cadmium	5	5
Copper	140	280
Nickel	56	112
Zinc	280	560

(17) Minnesota

Minnesota Pollution Control Agency, Water Quality Division. 1987. Sewage sludge management rules. Chapter 7040. Minnesota Pollution Control Agency, 520 Lafayette Road, St. Paul, Minnesota 55155.

Sewage sludge may not be applied to land used for growing food crops for humans if the cumulative amounts of metals added exceed the established criteria (Table 10). The soil and sludge mixture must be no lower than pH 6.5 during the growing season following application.

Table 10. *Maximum cumulative addition of metals from sewage sludge that may be added to Minnesota soils used for growing food crops (from Minnesota Pollution Control Agency 1987).*

Metal	Soil cation exchange capacity (meq/100 g)		
	<5	5–15	>15
Cadmium	5	10	20
Copper	140	280	560
Lead	560	1,120	2,240
Nickel	56	112	224
Zinc	280	560	1,120

(18) Missouri

Missouri Department of Natural Resources, Division of Environmental Quality. 1988. Agricultural use of municipal wastewater sludge – a planning guide. Missouri Department of Natural Resources, P.O. Box 176, Jefferson City, Missouri 65102.

Missouri guidelines for the disposal of sewage sludge on farmland were designed to prevent toxicity to plants and animals (Table 11). Annual applications should be no more than 10% of the cumulative amounts. For fruits and vegetables the maximum cumulative amount added is 800 kg/ha lead, and the maximum annual addition of cadmium is 0.5 kg/ha.

Table 11. *Maximum cumulative addition of metals (kg/ha) from sewage sludge recommended for privately owned Missouri farmland (from Missouri Department of Natural Resources 1988).*

	Soil cation exchange capacity (meq/100 g)		
Metal	<5	5–15	>5
Cadmium	5	10	20
Chromium	560	1,120	2,250
Copper	140	280	560
Lead	560	1,120	2,240
Nickel	140	280	560
Zinc	280	560	1,120

Additional guidelines were developed for the application of other metals in sewage sludge to soils on which crops will not be grown for direct human consumption. In addition to the values shown in Table 12, the amount of PCB's added should not exceed 1.1 kg/ha, and the concentration of dioxin in soil should not exceed 0.3 ppb.

Table 12. *Suggested safe applications (kg/ha) of trace compounds to Missouri soils without further investigations (from Missouri Department of Natural Resources 1988).*

Element	Maximum cumulative addition
Aluminum	4,480
Arsenic	112
Beryllium	112
Cobalt	56
Fluoride	896
Manganese	179
Molybdenum	9
Selenium	18

(19) New York

New York State Department of Environmental Conservation. 1988. Revised 6 NYCRR, Part 360. Solid waste management facilities (draft). New York State Department of Environmental Conservation, 50 Wolf Road, Albany, New York 12233.

Cumulative loading limits for the addition of metals in sewage sludge to land in New York were determined with consideration of human health, animal health, and effects on soil biota and plants (Table 13). The soil groups refer to a classification by the New York State Department of Agriculture and Markets. Soils of groups 1–3 tend to be more productive and stable than those of groups 4–10. In addition to the elements shown, chromium and mercury may be limited to protect groundwater.

Table 13. *Cumulative amounts of metals per hectare that may be added to New York State soils with sewage sludge (from New York Department of Environmental Conservation 1988).*

	Agricultural soils		Dedicated lands
Metal	Groups 1–3	Groups 4–10	(Forests, etc.)
Cadmium	3.4	4.5	11
Chromium	336	500	—
Copper	84	125	280
Lead	336	500	1,120
Nickel	34	50	168
Zinc	168	250	560

(20) Oregon

Oregon Department of Environmental Quality. 1984. Oregon Administrative Rules, Chapter 340, Division 50. Land application and disposal of sewage treatment plant sludge and sludge-derived products including septage. Oregon Department of Environmental Quality, 811 SW Sixth Avenue, Portland, Oregon 97204.

Table 14. *Maximum heavy metal loading (kg/ha) recommended for sludge applications to privately owned Oregon farmland (from Oregon Department of Environmental Quality 1984).*

	Soil cation exchange capacity (meq/100 g)		
Metal	<5	5–15	>15
Cadmium[a]	5	10	20
Copper	125	250	500
Lead	500	1,000	2,000
Nickel	50	100	200
Zinc	250	500	1,000

[a] The maximum application of cadmium for soils with pH values of 6.5 or less is 5 kg/ha regardless of the CEC.

(21) Vermont

Vermont Agency of Environmental Conservation. 1984. Draft guidelines for the treatment and utilization or disposal of sewage sludge. Agency of Natural Resources, 103 South Main Street, Waterbury, Vermont 05676.

Sewage sludge may not be spread on land if the maximum cumulative amounts exceed the established criteria shown in Table 15.

Table 15. *Maximum cumulative additions (kg/ha) of metals from sewage sludge that may be added to Vermont soils, by soil texture (from Vermont Agency of Environmental Conservation 1984).*

Metal	Loamy sand, sandy loam	Fine sandy loam, loam, silt loam	Clay loam, clay, silty clay
Cadmium	6	11	22
Chromium	140	280	560
Copper	140	280	560
Lead	200	400	800
Mercury	6	11	22
Nickel	56	112	224
Zinc	280	560	1,120

(22) Wisconsin

Wisconsin Department of Natural Resources. 1985. NR 204.07. Wisconsin Department of Natural Resources, Box 7921, Madison, Wisconsin 53707.

Sewage sludge may not be spread on land if the maximum cumulative amounts exceed the established criteria shown in Tables 16 and 17.

Radium-226 is sometimes a contaminant of water supplies. The disposal of sewage sludge containing at least 2 pCi/g (dry weight) of radium-226 must not result in soil concentrations that exceed 2 pCi/g.

Table 16. *Maximum cumulative additions (kg/ha) of cadmium from sewage sludge that may be added to Wisconsin soils (from Wisconsin Department of Natural Resources 1985).*

	Soil cation exchange capacity (meq/100 g)		
Soil pH	<5	5–15	>15
<6.5	5	5	5
>6.5	5	10	20

Table 17. *Maximum cumulative applications (kg/ha) of lead, zinc, copper, and nickel from sewage sludge that may be added to Wisconsin soils (from Wisconsin Department of Natural Resources 1985).*

	Soil cation exchange capacity (meq/100 g)			
Metal	<5	5–10	11–15	>15
Copper	125	250	375	500
Lead	500	1,000	1,500	2,000
Nickel	50	100	150	200
Zinc	250	500	750	1,000

(23) European Economic Community

European Economic Community. 1986. Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. Official Journal of the European Communities. No. L 181. 6–12.

To prevent injury to soil, plants, animals, and humans, the Council of the European Communities has set criteria limiting the addition of elements to land used for growing commercial food crops (Table 18).

Table 18. *Soil limit values determined by the Council of European Communities for the addition of heavy metals from sewage sludge to soil with a pH of 6.0–7.0 (from European Economic Community 1986).*

Element	Limit values[a] (ppm)
Cadmium	1–3
Copper[b]	50–140
Lead	50–300
Mercury	1–1.5
Nickel[b]	30–75
Zinc[b]	150–300

[a] "Member States may permit the limit values they fix to be exceeded in the case of the use of sludge on land which at the time of notification of this Directive is dedicated to the disposal of sludge but on which commercial food crops are being grown exclusively for animal consumption. Member States must inform the Commission of the number and type of sites concerned. They must also seek to ensure that there is no resulting hazard to human health or the environment."

[b] "Member States may permit the limit values they fix to be exceeded in respect of these parameters on soil with a pH consistently higher than 7. The maximum authorized concentrations of these heavy metals must in no case exceed those values by more than 50%. Member States must also seek to ensure that there is no resulting hazard to human health or the environment and in particular to groundwater."

Sewage Sludge Analyses

(24) U.S. Environmental Protection Agency

Fricke, C., C. Clarkson, E. Lomnitz, and T. O'Farrel. 1985. Comparing priority pollutants in municipal sludges. Biocycle 26:35–37.

Table 19. *Analyses of sewage sludges from 50 publicly owned treatment works by the U.S. Environmental Protection Agency (from Fricke et al. 1985).*

Pollutant category	Mean concentration (ppm; dry weight)	Pollutant category	Mean concentration (ppm; dry weight)
Metals and cyanide		**Base neutral compounds**	
Arsenic	5.9	Benzo(a)anthracene	9.1
Beryllium	1.2	Benzo(a)pyrene	256.6
Cadmium	32.2	Benzo(b)fluoranthene	1.76
Chromium	427.9	bis(2-ethylhexy)phthalate	157.6
Copper	562.4	Chrysene	8.3
Cyanide	748.5	Pyrene	6.8
Lead	378.0	3,3′-Dichlorobenzidine	1.64
Mercury	2.8	Hexachlorobenzene	1.25
Nickel	133.9	Hexachlorobutadiene	4.5
Selenium	2.6	n-Nitrosodiphenylamine	0.04
Zinc	1,409.2	Phenanthrene	5.9
Volatile compounds		**Pesticides and PCB's**	
Benzene	1.46	Aldrin	ND[a]
Carbon tetrachloride	4.48	Chlordane	ND
Chlorobenzene	1.16	DDD	ND
Chloroform	0.85	DDE	0.06
1,2-Dichloroethane	25.03	DDT	ND
Methylene chloride	8.65	Dieldrin	0.02
Tetrachloroethylene	3.47	Endrin	ND
Toluene	1,718.8	Heptachlor	0.02
Trichloroethylene	9.10	Lindane	0.02
Vinyl chloride	35.4	PCB's	ND
		Toxaphene	ND
Acid compounds			
Pentachlorophenol	10.4		
Phenol	19.3		
2,4,6-Trichlorophenol	2.3		

[a] ND = no data.

(25) Missouri

Missouri Department of Natural Resources, Division of Environmental Quality. 1985. Agricultural use of municipal wastewater sludge – a planning guide. Missouri Department of Natural Resources, P.O. Box 176, Jefferson City, Missouri 65102.

Table 20. *Analyses of 74 Missouri sewage sludges (from Missouri Department of Natural Resources 1985).*

Substance	Median (ppm; dry weight)	Range (ppm; dry weight)
Arsenic	6.1	2–39
Beryllium	0.6	0.2–3.4
Boron	33	8.7–380
Cadmium	8.1	1.7–320
Calcium	39,000	13,000–280,000
Chlordane	2.75	0.46–12
Chromium	85.5	10–12,000
Copper	390	45–5,200
Iron	16,000	3,000–41,000
Lead	145	42–960
Magnesium	4,700	1,500–21,000
Manganese	460	60–6,800
Mercury	3.9	0.6–130
Nickel	33.5	10–13,000
Nitrogen	27,000	4,000–53,000
PCB's	0.99	0.11–2.9
Phosphorus	16,000	3,500–51,000
Potassium	2,650	250–11,000
Selenium	3	1–25
Sodium	1,450	210–50,000
Zinc	1,200	170–13,000

Elemental Concentrations in Surficial Materials

United States

(26) Shacklette, H. T., J. C. Hamilton, J. G. Boerngen, and J. M. Bowles. 1971. Elemental composition of surficial materials in the conterminous United States. U.S. Geological Survey Professional Paper 574-D. U.S. Government Printing Office, Washington, D.C. 71 pp.

Table 21. *Averages and ranges (ppm) of concentrations of elements in soils and other surficial materials in the United States (from Shacklette et al. 1971).*

Element	Mean	Range	Element	Mean	Range
Aluminum	66,000	700– >100,000	Molybdenum	—	<3–7
Barium	554	15–5,000	Neodymium	45	<70–300
Beryllium	1	<1–7	Neptunium	13	<10–100
Boron	34	<20–300	Nickel	20	<5–700
Calcium	24,000	<150–320,000	Phosphorus	420	20–6,000
Cerium	86	<150–300	Potassium	23,000	50–70,000
Chromium	53	1–1,500	Scandium	10	<5–50
Cobalt	10	<3–70	Sodium	12,000	<500–100,000
Copper	25	<1–300	Strontium	240	<5–3,000
Gallium	19	<5–70	Titanium	3,000	300–15,000
Iron	25,000	100– >100,000	Vanadium	76	<7–500
Lanthanum	41	<30–200	Ytterbium	4	<1–50
Lead	20	<10–700	Yttrium	29	<10–200
Magnesium	9,200	50–100,000	Zinc	54	<25–2,000
Manganese	560	<1–7,000	Zirconium	240	<10–2,000

Sediment Guidelines

United States

(27) Great Lakes Harbors

U.S. Environmental Protection Agency. 1977. Unpublished guidelines. Region 5. 230 S. Dearborn, Chicago, Illinois 60604.

Table 22. *Guidelines for the pollutional classification of Great Lakes harbor sediments (from U.S. Environmental Protection Agency 1977).*

Contaminant	Nonpolluted (ppm; dry weight)	Moderately polluted (ppm; dry weight)	Heavily polluted (ppm; dry weight)
Ammonia	<75	75–200	>200
Arsenic	<3	3–8	>8
Barium	<20	20–60	>60
Cadmium	NE[a]	NE[a]	>75
Chemical oxygen demand	<40,000	40,000–80,000	>80,000
Chromium	<25	25–75	>75
Copper	<25	25–50	>50
Cyanide	<0.10	0.1–0.25	>0.25
Iron	<17,000	17,000–25,000	>25,000
Lead	<40	40–60	>60
Manganese	<300	300–500	>500
Mercury	<1	1	>1
Nickel	<20	20–50	>50
Phosphorus	<420	420–650	>650
PCB's	<1	1–10	>10
Volatile solids	<50,000	50,000–80,000	>80,000
Zinc	<90	90–200	>200

[a] NE = guidelines not established.

(28) Wisconsin

Wisconsin Department of Natural Resources. 1985. Report of the technical subcommittee on determination of dredge material suitability for in-water disposal. Madison, Wisconsin 53707.

Disposal of sediments in water is prohibited if concentrations of any of the contaminants are more than 125% of the criteria or if the concentrations of three or more contaminants are more than 110% of the criteria. If one or two contaminants are found at concentrations in the range of 110–125% of the criteria then a decision will be made for that particular case.

Table 23. *Wisconsin interim criteria for sediments from Great Lakes harbors for disposal in water (from Wisconsin Department of Natural Resources 1985).*

Contaminant category	Criteria not to be exceeded (ppm; dry weight)
Pesticides	
Aldrin	0.01
Chlordane	0.01
DDT	0.01
Dieldrin	0.01
Endrin	0.05
Heptachlor	0.05
Lindane	0.05
Toxaphene	0.05
Other organics	
PCB's	0.05
2,3,7,8 TCDD	1.0 pg/g[a]
2,3,7,8 TCDF	1.0 pg/g
Metals	
Arsenic	10
Barium	500
Cadmium	1.0
Chromium	100
Copper	100
Lead	50
Mercury	0.1
Nickel	100
Selenium	1.0
Zinc	100
Oil and grease	1,000

[a] Picograms per gram.

(29) Ontario

Dredging Subcommittee. 1986. A forum to review confined disposal facilities for dredged materials in the Great Lakes. Submitted to the Great Lakes Water Quality Board, 31 October 1986.

Table 24. *Ontario Ministry of the Environment guidelines for open lake disposal of sediments.*

Contaminant or measurement	Guideline (ppm[a])
Arsenic	8
Cadmium	1
Chromium	25
Copper	25
Lead	50
Mercury	0.3
Nickel	25
PCB's	0.05
Zinc	100
Total phosphorus	1,000
Oil and grease	1,500
Kjeldahl nitrogen	2,000
Loss on ignition	6%[a]
Chemical oxygen demand	5%[a]

[a] Guidelines for loss on ignition and chemical oxygen demand are expressed as percentages.

Selected Citations on Earthworms

Contaminants in Earthworms

(30) Barker, R. J. 1958. Notes on some ecological effects of DDT sprayed on elms. J. Wildl. Manage. 22:269–274.

This pioneering paper established that earthworms may accumulate DDT from soil and thereby become lethal to American robins (*Turdus migratorius*) feeding on them long after the DDT had been applied.

(31) Bengtsson, G., G. Nordstrom, and S. Rundgren. 1983. Population density and tissue metal concentration of lumbricids in forest soils near a brass mill. Environ. Pollut. Ser. A Ecol. Biol. 30:87–108.

The authors demonstrated that earthworm densities were inversely related to soil metal concentrations near a brass mill. Zinc, copper, and lead were measured and it was concluded that high zinc concentrations were probably responsible for the population reductions.

(32) Beyer, W. N., and C. D. Gish. 1980. Persistence in earthworms and potential hazards to birds of soil applied DDT, dieldrin, and heptachlor. J. Appl. Ecol. 17:295–307.

Beyer, W. N., and A. J. Krynitsky. 1989. Long-term persistence of dieldrin, DDT, and heptachlor epoxide in earthworms. Ambio 18:271–273.

The authors applied DDT, dieldrin, and heptachlor to separate plots in amounts of 0.6, 2.2, or 9.0 kg/ha. For 11 years, the authors analyzed earthworms and soils for residues. The average ratios of residues in earthworms (dry weight) to residues in soil (dry weight) were: total DDT, 5; dieldrin, 8; and heptachlor epoxide, 10. The average times for the residues in earthworms to be reduced by half were: total DDT, 3.2 years; dieldrin, 2.6 years; and heptachlor epoxide, 3.0 years. The potential hazards to birds are discussed. The second paper showed that over 20 years the average times for the residues in earthworms to be reduced by half were: DDE, 5.7 years; dieldrin, 5.4 years; and heptachlor epoxide, 4.3 years. These data refer to the plots treated at 9.0 kg/ha.

(33) Davis, B. N. K. 1971. Laboratory studies on the uptake of dieldrin and DDT by earthworms. Soil Biol. Biochem. 3:221–233.

The dieldrin concentration factor (expressed as dry weight of earthworms) of *Lumbricus terrestris* was 2.4 and of *Allolobophora caliginosa* was 5.6 when these earthworms were kept under laboratory conditions in compost containing 17 ppm dieldrin. *A. caliginosa* accumulated 0.5, 6.9, 37, and 159 ppm (dry weight) total DDT (DDT, DDE, and TDE) from compost containing 1, 4, 16, and 64 ppm DDT. Accumulation of DDT by earthworms was inversely correlated with soil organic matter content.

(34) Diercxsens, P., D. de Weck, N. Borsinger, B. Rosset, and J. Tarradellas. 1985. Earthworm contamination by PCBs and heavy metals. Chemosphere 14:511–522.

Concentrations of PCB congeners in earthworms (wet weight) from a vineyard treated with compost were, on average, 5 or 6 times as great as the concentrations in the upper 20 cm of soil (dry weight). At a control site the concentrations in earthworms were about 1.3 times that in soil.

(35) Forsyth, D. J., T. J. Peterle, and L. W. Bandy. 1983. Persistence and transfer of ^{36}Cl-DDT in the soil and biota of an old-field ecosystem: a six-year balance study. Ecology 64:1620–1636.

The authors applied radioactively labeled DDT to a field and estimated DDT concentrations in soils, plants, and animals over 5 years. The results may be useful in making risk assessments because the DDT concentrations in soils and earthworms can be related to those in other organisms included in the study.

(36) Gish, C. D. 1970. Organochlorine insecticide residues in soils and soil invertebrates from agricultural lands. Pestic. Monit. J. 3:241–252.

The author collected earthworms from 67 agricultural fields and analyzed them for organochlorine insecticides. The average concentration factor (dry weight) was 9.0 for DDT and its metabolites, and the average soil concentration was 1.36 ppm DDT. Additional data are included on aldrin, dieldrin, endrin, heptachlor, and chlordane, which were detected at much lower concentrations, and on concentrations of these insecticides in a few other kinds of soil invertebrates.

(37) Haque, A., and W. Ebing. 1988. Uptake and accumulation of pentachlorophenol and sodium pentachlorophenate by earthworms from water and soil. Sci. Total Environ. 68:113–125.

After a 2-week exposure to either 2.2 ppm (dry weight) or 11.2 ppm radioactively labeled sodium pentachlorophenate (and its metabolites) in artificial soil under laboratory conditions, earthworms (*Allolobophora caliginosa*) accumulated 82.5 ppm (dry weight, whole earthworm, including gut contents) or 558.5 ppm pentachlorophenate (and metabolites). The corresponding bioconcentration factors are 8.0 for the lower concentration and 12.8 for the higher concentration. When earthworms were exposed to 1.8 ppm in outdoor soil, *Allolobophora caliginosa* had a bioconcentration factor of 6.3, and *Lumbricus terrestris* had a bioconcentration factor of 22.2.

(38) Jeffries, D. J., and B. N. K. Davis. 1968. Dynamics of dieldrin in soil, earthworms, and song thrushes. J. Wildl. Manage. 32:441–456.

Earthworms (predominantly *Lumbricus terrestris*) kept in laboratory compost containing 25 ppm dieldrin accumulated from 18.4 ppm to 24.4 ppm (wet weight) dieldrin after 20 days. A song thrush (*Turdus philomelos*) fed a diet of earthworms containing 12.38 ppm dieldrin died in 8 days. Song thrushes fed diets of earthworms containing from 0.32 ppm to 5.69 ppm dieldrin for 6 weeks accumulated from 0.09 ppm to 4.03 ppm dieldrin. A thrush consuming 5.69 ppm dieldrin survived but accumulated what would be a lethal concentration if it had metabolized its fat reserves.

(39) Korschgen, L. J. 1971. Disappearance and persistence of aldrin after five annual applications. J. Wildl. Manage. 35:494–500.

The residues of aldrin and dieldrin from aldrin-treated soil were studied in earthworms and soil for 6 years. The combined concentrations remained relatively constant throughout the study and were on average 0.11 ppm (wet weight) in soil and 0.61 ppm (wet weight) in earthworms.

(40) Kreis, B., P. Edwards, G. Cuendet, and J. Tarradellas. 1987. The dynamics of PCB's between earthworm populations and agricultural soils. Pedobiologia 30:379–388.

The authors found that adult earthworms (*Nicodrilus*) accumulated an average of 78 ppb PCB's from surface soil containing 6.8 ppb PCB's (sewage sludge added), and 19 ppb PCB's from surface soil containing 2.6 ppb PCB's (no sewage sludge added). The authors also describe the distribution of specific congeners and explain how the feeding habits of different species are related to their uptake of PCB's.

(41) Ma, W. 1987. Heavy metal accumulation in the mole, *Talpa europea*, and earthworms as indicators of metal bioavailability in terrestrial environments. Bull. Environ. Contam. Toxicol. 39:933–938.

This article relates concentrations of metals in earthworms and soil to those in moles, an earthworm predator. For example, at study site 2, where the soil contained 6.0 ppm cadmium and earthworms contained 79 ppm cadmium (dry weight), the moles had 224 ppm in their kidneys (dry weight) and 227 ppm in their livers (dry weight). Data on copper, lead, and zinc are also included.

(42) Marquenie, J. M., J. W. Simmers, and S. H. Kay. 1987. Preliminary assessment of bioaccumulation of metals and organic contaminants at the Times Beach Confined Disposal Site, Buffalo, N.Y. Miscellaneous paper EL-87-6, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss. 67 pp.

The authors collected soils and native earthworms from a confined disposal facility containing contaminated dredged materials and from a reference site. Earthworms (*Eisenia foetida*) were kept in 15 samples of the soils collected at different points for 32 days to measure uptake of contaminants (Table 25). The median concentration factor (concentration in earthworms, ash-free dry weight, divided by the concentration in soil, dry weight) was approximately 6 for the sum of 9 PCB components for the 15 soils.

(43) Martinucci, G. B., P. Crespi, P. Omodeo, G. Osella, and G. Traldi. 1983. Earthworms and TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin) in Seveso. Pages 275–283 *in* J. E. Satchell, ed. Earthworm ecology, from Darwin to vermiculture. Chapman and Hall, New York. 495 pp.

The authors studied earthworms and soils in Sevesco, Italy, the site of a chemical plant accident that led to substantial contamination of the soil with TCDD. The correlation between concentrations of TCDD in soil and earthworms was excellent. On average, the concentrations in earthworms (wet weight) were 14.5 times those in soil. At the most contaminated site the soils contained from 6 to 9 ppb and the earthworms from 70 to 250 ppb.

Table 25. *Concentrations of PAH's in bioassay earthworms* (Eisenia foetida) *and bioassay soil from 15 sites at the Times Beach Confined Disposal Facility in Buffalo, N.Y. (from Marquerie et al. 1987).*

Contaminant	Soil mean (ppm; dry weight)	Soil range (ppm; dry weight)	Earthworms mean (ppm; ash-free dry weight)	Earthworms range (ppm; ash-free dry weight)
Anthanthrene	1.2	0.092–2.5	0.11	<0.003–0.60
Anthracene	0.92	0.10–1.5	0.047	0.008–0.37
Benzo(a)anthracene	2.0	0.22–4.5	0.25	0.093–1.7
Benzo(a)pyrene	3.8	0.36–8.6	1.3	0.14–7.4
Benzo(b)fluoranthene	2.6	0.25–5.6	0.83	0.15–5.4
Benzo(b)fluorene	0.72	0.06–6.1	—	— 0.77
Benzo(e)pyrene	2.1	0.22–4.0	0.91	0.099–4.2
Benzo(g,h,i)perylene	4.5	0.29–7.9	1.1	0.50–3.5
Benzo(j)fluoranthene	<1.0	<1.0–<1.0	<0.1	<0.1–<0.1
Benzo(k)fluoranthene	1.5	0.14–2.9	0.38	0.10–2.7
Chrysene	2.0	0.19–4.6	0.35	0.15–1.7
Dibenzo(a,i)pyrene	1.4	0.29–2.6	0.44	0.076–1.4
Dibenzo(a,j)anthracene	0.87	0.13–1.9	0.32	0.050–0.73
3,6- Dimethylphenanthrene	<0.04	<0.04–0.72	0.10	<0.004–0.51
Fluoranthene	2.4	0.19–7.5	0.19	<0.12–2.4
Indeno(1,2,3- c,d)pyrene	3.1	0.47–6.7	1.3	0.21–5.0
3- Methylcholanthrene	<0.025	<0.025–0.81	<0.003	<0.003–0.02
Perylene	1.2	0.12–2.8	0.30	0.036–1.8
Phenanthrene	2.3	0.41–4.8	0.28	0.091–1.4
Pyrene	2.5	<0.15–6.1	0.23	<0.015–4.5
Triphenylene	1.3	<0.15–26.0	0.87	<0.015–12.0

(44) Neuhauser, E. F., R. C. Loehr, M. R. Malecki, D. L. Milligan, and P. R. Durkin. 1985. The toxicity of selected organic chemicals to the earthworm *Eisenia fetida*. J. Environ. Qual. 14:383–388.

The authors estimated the LC50's of earthworms (*Eisenia foetida*) for 10 chemicals in an artificial soil medium in a 2-week test (Table 26).

(45) Neuhauser, E. F., R. C. Loehr, D. L. Milligan, and M. R. Malecki. 1985. Toxicity of metals to the earthworm *Eisenia fetida*. Biol. Fertil. Soils 1:149–152.

The authors measured the mortality of earthworms from five metals (nitrate salts) in an artificial soil mix in a 2-week test. The LC50's were as follows: cadmium, 1,843 ppm; copper, 643 ppm; lead, 5,941 ppm; nickel, 757 ppm; and zinc, 662 ppm. The results may be difficult to apply to field situations because of the shortness of the exposure time and because the chemical form of the metals in soil would be quite different.

Table 26. *LC50's of earthworms (*Eisenia foetida*) for 10 chemicals (from Neuhauser et al. 1985).*

Chemical	LC50 (ppm)
Chloroacetamine	26
4-Nitrophenol	38
2,4,6 Trichlorophenol	58
Carbaryl	106
n-Nitrosodiphenylamine	151
Fluorene	173
Phenol	401
2-Chloroethyl vinyl ether	740
Dimethyl phthalate	3,160
1,2 Dichloropropane	4,240

(46) Pimentel, D., D. Culliney, M. N. Burgess, G. S. Stoewsand, J. L. Anderson, C. A. Bache, W. H. Gutenmann, D. J. Lisk. 1984. Cadmium in Japanese quail fed earthworms inhabiting a golf course. Nutr. Rep. Int. 30:475–481.

Earthworms collected from a golf course treated with fungicides containing cadmium and with composted sewage sludge contained an average of 48 ppm (dry weight) cadmium. The earthworms were freeze-dried and fed to European quail as 50% of their diet. The males accumulated 14 ppm and the females 18 ppm in their kidneys (dry weight). These values are well above what would be expected in control quail.

(47) Reinecke, A. J., and G. Nash. 1984. Toxicity of 2,3,7,8-TCDD and short-term bioaccumulation by earthworms (Oligochaeta). Soil Biol. Biochem. 16:45–49.

In an 85-day laboratory study, the soil concentration of TCDD lethal to the earthworm *Allolobophora caliginosa* was estimated to be between 5 and 10 ppm. After 20 days, the ratio of TCDD in earthworms (wet weight) to that in soil (dry weight) was 9.4 for soil containing 0.05 ppm, 0.68 for soil containing 0.5 ppm, 0.64 for soil containing 1.5 ppm, and 0.47 for soil containing 5.0 ppm. Concentrations in earthworms were lower than these after 85 days. The authors generalized that TCDD accumulated to about 5 times the soil concentrations within 7 days at 0.05 ppm, but at higher soil concentrations there was no bioaccumulation, presumably because TCDD was excreted.

(48) Reinecke, A. J., and J. M. Venter. 1985. Influence of dieldrin on the reproduction of the earthworm *Eisenia fetida* (Oligochaeta). Biol. Fertil. Soils 1:39–44.

The authors showed that concentrations of 10–100 ppm dieldrin in soil decreased cocoon production by *Eisenia foetida* in laboratory cultures.

(49) Ruppel, R. F., and C. W. Laughlin. 1977. Toxicity of some soil pesticides to earthworms. J. Kans. Entomol. Soc. 50:113–118.

The authors measured mortality of earthworms exposed to various insecticides under both laboratory and field conditions. The laboratory results are shown in Table 27. The carbamates tended to be more toxic than the other classes of insecticides.

Table 27. *Estimated amount of soil insecticides causing 50% mortality of night crawlers (from Ruppel and Laughlin 1977).*

Insecticide	kg/ha	Class
Ethoprop 10%G	5.08	Phosphate
Aldicarb 10%G	6.40	Carbamate
Tirpate 10%G	8.47	Carbamate
Carbofuran 10%G	9.06	Carbamate
Bufencarb 10%G	10.2	Carbamate
Methomyl 90%SP	11.6	Carbamate
Oxamyl 2.0 EC	14.6	Carbamate
Propoxur 15%G	20.2	Carbamate
Dyfonate 20%G	28.2	Phosphate
Phorate 15%G	33.2	Phosphate
Chlorpyrifos 10%G	>36	Phosphate
Terbufos 15%G	>36	Phosphate
Nemacur 15%G	>36	Phosphate
Disulfoton 15%G	>36	Phosphate
Dasanit 15%G	>36	Phosphate
Chlordane 33.3%G	>36	Chlorinated hydrocarbon
Diazinon 14%G	>36	Phosphate
Landrin 15%G	>36	Carbamate
Phosalone 3.0EC	>36	Phosphate
Promecarb 10%G	>36	Carbamate
Bay 92114 10%G	>36	Phosphate
TH6040 25%WP	>36	Urea compound
CGA 12223 15%	>36	Phosphate

(50) Stickel, W. H., D. W. Hayne, and L. F. Stickel. 1965. Effects of heptachlor-contaminated earthworms on woodcocks. J. Wildl. Manage. 29:132–146.

When 12 American woodcocks (*Scolopax minor*) were fed earthworms containing an average of 2.86 (wet) heptachlor epoxide, 6 of the birds died within 35 days. No control birds died. Heptachlor epoxide at 0.65 ppm was not lethal to well-fed birds, but when earthworm rations were later reduced the residues stored by the woodcock became lethal. This study demonstrated how applications of heptachlor were causing wildlife mortality.

(51) Stoewsand, G. S., C. A. Bache, W. H. Gutenmann, D. J. Lisk. 1986. Concentration of cadmium in Coturnix quail fed earthworms. J. Toxicol. Environ. Health 18:369–376.

The authors collected earthworms from soils not known to be contaminated with cadmium and mixed them into a diet for European quail. The whole diet contained 2 ppm cadmium. After 63 days the mean renal cadmium concentration of the quail was 2.75 ppm in males and 2.11 ppm in females. The mean renal concentration was 0.19 ppm in control males and 0.23 in control females.

(52) Thompson, A. R. 1971. Effects of nine insecticides on the numbers and biomass of earthworms in pasture. Bull. Environ. Contam. Toxicol. 5:577–586.

The authors counted the numbers of earthworms alive in plots after treatment with each of nine insecticides. Dursban (2 lb/acre), Bayer 37289 (3 lb/acre), and DDT (5 lb/acre) had little if any effect; Bux (1 lb/acre), endrin (1 lb/acre), and carbaryl (2 lb/acre) had some effect; and Dasanit (3 lb/acre), carbofuran (4 lb/acre), and Stauffer N-2596 (2 lb/acre) drastically reduced earthworm populations.

(53) Venter, J. M., and A. J. Reinecke. 1985. Dieldrin and growth and development of the earthworm, *Eisenia fetida* (Oligochaeta). Bull. Environ. Contam. Toxicol. 35:652–659.

The accumulation of dieldrin by *Eisenia foetida* after 90 days in laboratory soil was as follows: 4.6 ppm (wet weight) from 10 ppm, 9.7 ppm from 30 ppm, 12.4 ppm from 50 ppm, and 13.9 ppm from 100 ppm. All soil concentrations tested had at least a slight effect on the rate of development of the clitellum, which is the band around earthworms that indicates maturity.

(54) Wheatley, G. A., and J. A. Hardman. 1968. Organochlorine insecticide residues in earthworms from arable soils. J. Sci. Food Agric. 19:219–225.

The authors collected earthworms from agricultural soils treated with organochlorine insecticides. The mean concentration factors (concentration in earthworms, wet weight, to soil, dry weight) for six species of earthworms ranged from 0.97 to 4.0 for aldrin and dieldrin combined (soil concentration = 1.36 ppm), from 1.2 to 4.9 for total DDT (soil DDT = 0.94 ppm), and from 1.5 to 4.2 for gamma BHC (soil concentration = 0.004 ppm). Based on 90 pairs of data values, the authors generalized that concentration factors of organochlorine insecticides were dependent on soil concentrations, decreasing from about 5 to 10 when soil concentrations were 0.001–0.01 ppm, to less than 1 when soil concentrations were about 10 ppm.

(55) Yadav, D. V., P. K. Mittal, H. C. Agarwal, and M. K. K. Pillai. 1981. Organochlorine insecticide residues in soil and earthworms in the Delhi area, India, August–October, 1974. Pestic. Monit. J. 15:80–85.

At 48 sites in the Delhi area of India the soil concentrations of total DDT were in the range of 0.01–2.61 ppm. Corresponding concentrations in earthworms (*Pheretima posthuma*) were in the range of 0.10–37.74 ppm (presumably wet weight). The median of the 48 ratios was 7.0.

Elements in Earthworms

(56) Guide to the Literature on the Accumulation of Elements in Earthworms

Papers on the accumulation of elements by earthworms are helpful in evaluating environmental contaminants in soil because earthworms are closely associated with both the soil and many wildlife predators. So many articles have been published on this subject, however, that they will not all be discussed separately. Some of the problems in interpreting concentrations in earthworms are as follows:

- Ecological variables, such as soil characteristics, may obscure the underlying relation between concentrations in soils and in earthworms. Earthworms are best used as indicators of contamination when the same species from contaminated and uncontaminated, but similar, soils can be compared.

- Earthworms from uncontaminated soils may have very high concentrations of some elements (Beyer and Cromartie 1987).

- Earthworms probably regulate copper, selenium, and zinc in their tissue (Beyer and Cromartie 1987). For these elements the concentration factors vary with soil concentrations.

- Earthworms feed selectively on plant debris and soil organic matter and, consequently, a soil sample may not adequately represent the exposure of a contaminant to earthworms.

- It is not known how readily available the metals in earthworms are to predators. This may be particularly important when evaluating elements that are found mainly in the soil in the gut of earthworms rather than in earthworm tissue.

All of the articles on cadmium agree that cadmium is greatly concentrated in earthworms relative to soil. A typical concentration factor (concentration in earthworms, dry weight, to concentration in soil, dry weight) for soils containing a few ppm is 21 (Beyer et al. 1982). Cadmium has a half-time in earthworms estimated as 120 days (Helmke et al. 1979); consequently, short laboratory tests may give misleading results. A typical concentration factor for lead, in contrast, is 0.66 (Beyer et al. 1982). This means that if lead is a hazard to predators it is probably from lead in the soil in the gut of the earthworms. Earthworms of the genus *Eisenoides* (Beyer and Cromartie 1987) and, according to some findings, earthworms from very acid soils (Ireland and Wooten 1976; Morgan and Morgan 1988) are exceptions and may concentrate lead relative to soil. In general, the main environmental concern about earthworms and high soil metal concentrations is that the metals will accumulate to concentrations toxic to predators, rather than that the metals will be toxic to earthworms. Copper is an exception. Earthworms have been eliminated from soils because of copper contamination (Rhee 1975), and serious sublethal effects have been demonstrated at environmentally realistic concentrations (Ma 1984). The review by Ireland (1983) is excellent, and the work by Helmke et al. (1979) includes information on many elements.

The citations for a number of articles on the accumulation of elements by earthworms follow. For easier reference, the metallic elements discussed in each article are listed at the end of each citation.

Andersen, C. 1979. Cadmium, lead and calcium content, number and biomass, in earthworms (Lumbricidae) from sewage sludge treated soil. Pedobiologia 19:309–319. (cadmium, lead)

Ash, C. P. J., and D. L. Lee. 1980. Lead, cadmium, copper and iron in earthworms from roadside sites. Environ. Pollut. Ser. A Ecol. Biol. 22:59–67. (cadmium, copper, lead)

Beyer, W. N., R. L. Chaney, and B. M. Mulhern. 1982. Heavy metal concentrations in earthworms from soil amended with sewage sludge. J. Environ. Qual. 11:381–385. (cadmium, copper, lead, nickel, zinc)

Beyer, W. N., and E. J. Cromartie. 1987. A survey of Pb, Cu, Zn, Cd, Cr, As, and Se in earthworms and soil from diverse sites. Environ. Monit. Assess. 8:27–36. (cadmium, copper, chromium, lead, selenium, zinc)

Beyer, W. N., G. Hensler, and J. Moore. 1987. Relation of pH and other soil variables to concentrations of Pb, Cu, Zn, Cd, and Se in earthworms. Pedobiologia 30:167–172. (cadmium, copper, lead, selenium, zinc)

Gish, C. D., and R. E. Christensen. 1973. Cadmium, nickel, lead, and zinc in earthworms from roadside soil. Environ. Sci. & Technol. 7:1060–1062. (cadmium, copper, lead, selenium, zinc)

Hartenstein, R., E. F. Neuhauser, and J. Collier. 1980. Accumulation of heavy metals in the earthworm *Eisenia foetida*. J. Environ. Qual. 9:23–26. (cadmium, copper, lead, nickel, zinc)

Helmke, P. A., W. P. Robarge, R. L. Korotev, and P. J. Schomberg. 1979. Effects of soil-applied sewage sludge on concentrations of elements in earthworms. J. Environ. Qual. 8:322–327. (cadmium, chromium, mercury, selenium, zinc)

Honda, K., T. Nasu, and R. Tatsukawa. 1984. Metal distribution in the earthworm, *Pheretima hilgendorfi*, and their variations with growth. Arch. Environ. Contam. Toxicol. 13:427–432. (cadmium, copper, lead, mercury, nickel, zinc)

Ireland, M. P. 1975. Metal content of *Dendrobaena rubida* (Oligochaeta) in a base metal mining area. Oikos 26:74–79. (lead, zinc)

Ireland, M. P. 1975. Distribution of lead, zinc and calcium in *Dendrobaena rubida* (Oligochaeta) living in soil contaminated by base metal mining in Wales. Comp. Biochem. Physiol. 52B:551–555. (lead, zinc)

Ireland, M. P. 1979. Metal accumulation by the earthworms *Lumbricus rubellus*, *Dendrobaena veneta*, and *Eiseniella tetraedra* living in heavy metal polluted sites. Environ. Pollut. 19:201–206. (cadmium, copper, lead, zinc)

Ireland, M. P. 1983. Heavy metal uptake and tissue distribution in earthworms. Pages 247–265 *in* Earthworm ecology, from Darwin to vermiculture. Chapman and Hall, New York. 495 pp. (cadmium, copper, lead, zinc)

Ireland, M. P., and R. J. Wooton. 1976. Variations in the lead, zinc, and calcium content of *Dendrobaena rubida* (Oligochaeta) in a base metal mining area. Environ. Pollut. 10:201–208. (lead, zinc)

Ma, W. 1982. The influence of soil properties and worm-related factors on the concentration of heavy metals in earthworms. Pedobiologia 24:109–119. (cadmium, chromium, copper, lead, nickel, zinc)

Ma, W. 1984. Sublethal toxic effects of copper on growth, reproduction and litter breakdown activity in the earthworm *Lumbricus rubellus*, with observations on the influence of temperature and soil pH. Environ. Pollut. Ser. A Ecol. Biol. 33:207–219. (copper)

Ma, W., T. Edelman, I. van Beersum, and T. Jans. 1983. Uptake of cadmium, zinc, lead, and copper by earthworms near a zinc-smelting complex: influence of soil pH and organic matter. Bull. Environ. Contam. Toxicol. 30:424–427. (cadmium, copper, lead, zinc)

Morgan, J. E., and A. J. Morgan. 1988. Calcium-lead interactions involving earthworms. Part 1. The effect of exogenous calcium on lead accumulation by earthworms under field and laboratory conditions. Environ. Pollut. 54:41–53. (lead, selenium)

Morgan, J. E., and A. J. Morgan. 1988. Earthworms as biological monitors of cadmium, copper, lead, and zinc in metalliferous soils. Environ. Pollut. 54:123–138. (cadmium, copper, lead, zinc)

Nielsen, M. G., and G. Gissel-Nielsen. 1975. Selenium in soil-animal relationships. Pedobiologia 15:65–67. (selenium)

Van Hook, R. I. 1974. Cadmium, lead, and zinc distributions between earthworms and soils: potentials for biological accumulation. Bull. Environ. Contam. Toxicol. 12:509–512. (cadmium, lead, zinc)

van Rhee, J. A. 1975. Copper contamination effects on earthworms by disposal of pig waste in pastures. Pages 451–457 *in* Jan Vanek, ed. Progress in soil zoology. Dr. W. Junk, The Hague. (copper)

Wade, S. E., C. A. Bache, and D. J. Lisk. 1982. Cadmium accumulation by earthworms inhabiting municipal sludge-amended soil. Bull. Environ. Contam. Toxicol. 28:557–560. (cadmium)

Wright, M. A., and A. Stringer. 1980. Lead, zinc, and cadium content of earthworms from pasture in the vicinity of an industrial smelting complex. Environ. Pollut. Ser. A Ecol. Biol. 23:313–321. (cadmium, lead, zinc)

General Earthworm Biology

(57) Lee, K. E. 1985. Earthworms, their ecology and relationships with soil and land use. Academic Press, New York. 411 pp.

Macdonald, D. W. 1983. Predation on earthworms by terrestrial vertebrates. Pages 393–414 *in* J. E. Satchell, ed. Earthworm ecology, from Darwin to vermiculture. Chapman and Hall, New York. 495 pp.

Reynolds, J. W. 1977. The earthworms (Lumbricidae and Sparganophilidae) of Ontario. Life Sciences Miscellaneous Publications, Royal Ontario Museum, Toronto. 141 pp. (Excellent for identifying common earthworms)

Satchell, J. E., editor. 1983. Earthworm ecology, from Darwin to vermiculture. Chapman and Hall, New York. 495 pp.

Additional Literature

Metal Toxicity in Soil Litter

58) Beyer, W. N., G. W. Miller, and E. J. Cromartie. 1984. Contamination of the O2 soil horizon by zinc smelting and its effect on woodlouse survival. J. Environ. Qual. 13:247–251.

Beyer, W. N., and A. Anderson. 1985. Toxicity to woodlice of zinc and lead oxides added to soil litter. Ambio 14:173–174.

The authors collected litter samples at various distances from two zinc smelters and fed them to woodlice. Woodlouse mortality was shown to be related to the distance from the smelters. By adding metals artificially to control litter, the authors demonstrated that zinc concentrations near the smelter were adequate to account for the toxicity. Toxic effects of the zinc could be detected as far as 19 km from the smelters. Further studies showed that as little as 1,600 ppm zinc had negative effects on laboratory populations of woodlice, but that lead was much less toxic, and that its effects were observed only at 12,800 ppm.

Human Health Hazards

59) Chaney, R. L., and H. W. Mielke. 1986. Standards for soil lead limitations in the United States. Trace Subst. Environ. Health 20:357–377.

The authors reviewed literature suggesting that ingestion of contaminated soil and dust by children is the principal public health hazard from lead in soil. They estimated that average blood lead concentrations of children increase about 5 μg Pb/d*l* for each 1,000 ppm in soil or dust from their environment. They concluded that substantial areas in which soil lead concentrations exceeded 500 ppm ought to be cleaned up, and that for the children at greatest risk that as little as 150 ppm of lead in the soil may cause excessive concentrations of lead in their blood.

60) Davies, B. E., and B. G. Wixson. 1986. Lead in soil—how clean is clean? Trace Subst. Environ. Health 20:233–241.

The biological implications of lead in soil and the existing regulatory limits were discussed. Uncontaminated soils frequently were found to contain an average of about 40 ppm lead, and some contained as much as 120 ppm lead. Garden and yard soils typically contained 200–500 ppm lead. The authors suggested that regulatory criteria should be based on the ultimate use of the land, but that 1,000 ppm would be a prudent critical regulatory limit.

61) Kimbrough, R. D., H. Falk, and P. Stehr. 1984. Health implications of 2,3,7,8-tetrachlorodibenzodioxin (TCDD) contamination of residential soil. J. Toxicol. Environ. Health 14:47–93.

The authors modeled the exposure of humans to TCDD in soil. Based on the potential of TCDD to cause cancer, they concluded that a soil concentration of 1 ppb is a virtually safe dose. Their methods and supporting data are presented in detail.

PCB Ingestion by Grazing Animals

62) Fries, G. F. 1982. Potential polychlorinated biphenyl residues in animal products from application of contaminated sewage sludge to land. J. Environ. Qual. 11:14–20.

The author reviewed the literature to determine the relation of PCB's in soil to those in milk from dairy cattle grazing on land that had received applications of contaminated sewage sludge. He concluded that ingestion of soil contaminated with PCB's during grazing was a more important route of exposure than either ingestion of PCB's in sludge adhering to plants after application or ingestion of PCB's that were taken up by plants through their roots or adsorbed from the air. The fraction of soil ingested with the diet may be as high as 6% over a year or as high as 14% during the month of highest intake. PCB concentrations in milk fat were found to be about 4 or 5 times those in the diet. That means that 1 ppm PCB's in soil would be equivalent to 0.14 ppm in the diet during the worst month, and that the milk fat would contain about 0.7 ppm. PCB's in the body fat of nonlactating animals would be expected to accumulate in concentrations similar to those in milk fat. The procedures developed in this paper may be useful for evaluating other persistent organic chemicals as well.

Beyer, W. N. 1990. **Evaluating Soil Contamination.** U. S. Fish Wildl. Serv., *Biol. Rep.* 90(2). 25 pp.

This miscellaneous collection of information was brought together to help wildlife specialists who want a quick means of deciding how severely contaminated a soil is and who want to be able to put a particular soil contaminant concentration into perspective. Rather than set forth its own criteria, the work makes available to the reader a wide range of criteria, regulations, and opinions from related fields. Most of the entries do not refer to wildlife, but were selected because they provide the only guidance available. The work also provides the reader access to scientific articles, particularly those on bioaccumulation of contaminants from soil, which may be useful for making risk assessments. The entries may be accessed through an index of more than 200 contaminants.

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TAKE PRIDE
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U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

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